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Low resistance, unannealed ohmic contacts to n-type $InAs_{0.66}Sb_{0.34}$

J.G. Champlain, R. Magno and J.B. Boos

Unannealed Ti/Pt/Au contacts to n-type $InAs_{0.66}Sb_{0.34}$ were fabricated and measured. Extremely low specific contact resistances down to $2.4 \times 10^{-8}\ \Omega\ cm^2$ were measured, commensurate with $In_{0.53}Ga_{0.47}As$, InAs, and $In_{0.27}Ga_{0.73}Sb$ contact schemes with higher doping, which is due to the very high electron mobility in $InAs_{0.66}Sb_{0.34}$ and hypothesised pinning of the surface Fermi level within the conduction band.

Introduction: The 6.1 Å materials, as they are commonly referred to, InAs, AlSb, GaSb, and their alloys (e.g. $In_{0.2}Al_{0.8}Sb$, $InAs_{0.9}Sb_{0.1}$) have become highly desirable for use in low-power, high-speed electronic applications owing to a large range of available bandgaps and band offsets, and high electron and hole mobilities. The first monolithic microwave integrated circuits (MMICs) fabricated using 6.1 Å-based HEMTs have been demonstrated recently [1, 2]. New materials such as $In_xGa_{1-x}Sb$, $InAs_ySb_{1-y}$, and $In_xAl_{1-x}As_ySb_{1-y}$, with lattice constants ranging from 6.1 to 6.48 Å, show promise of further power reduction, due greatly to narrower bandgaps, while maintaining or possibly improving high-speed operation [3]. Initial work on HEMTs and InAs heterojunction bipolar transistors (HBTs) has been promising [1, 4–7], but the fabrication of 6.2 Å $In_{0.27}Ga_{0.73}Sb$ HBTs in this material system is relatively new.

A critical aspect of low-power, high-speed HBT operation is a low emitter and collector contact resistance. In this Letter, the electrical characteristics of n-type (Te-doped) $InAs_{0.66}Sb_{0.34}$ are examined as related to its application as an intermediate contact layer in 6.2 Å-based HBTs. Hall effect measurements in addition to sheet and contact resistance measurements have been performed to evaluate the n-type $InAs_{0.66}Sb_{0.34}$ material and the quality of unannealed Ti/Pt/Au contacts to it.

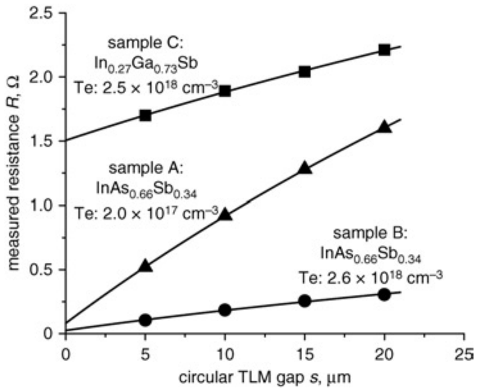

Fig. 1 *Plot of measured resistance (R) against gap spacing (s) of CTLM patterns for unannealed Ti/Pt/Au contacts on samples A, B, C*

Growth and fabrication: Bulk $InAs_{0.66}Sb_{0.34}$ samples were grown by solid-source molecular beam epitaxy (MBE). Structures consisted of a semi-insulating GaAs substrate, a 1.0 μm undoped AlSb buffer, and 1.0 μm n-type (Te-doped) $InAs_{0.66}Sb_{0.34}$. Two tellurium doping levels were examined: $2.0 \times 10^{17}\ cm^{-3}$ and $2.6 \times 10^{18}\ cm^{-3}$, hereon referred to as sample A and sample B, respectively. In addition to the $InAs_{0.66}Sb_{0.34}$ samples, a 0.5 μm n-type $In_{0.27}Ga_{0.73}Sb$ (Te: $2.5 \times 10^{18}\ cm^{-3}$) sample (sample C) was grown for comparison. Fabrication consisted of a single optical lithography step and e-beam evaporation of the Ti/Pt/Au (100/50/2500 Å) contact to form circular transmission line method (CTLM) patterns for contact resistance extraction. Hall effect measurement samples were simply fabricated by placing four indium dots at the corners of a separate 5 mm square portion of the growths.

Measurement, results, analysis: CTLM patterns were used to evaluate the sheet resistance of the n-type $InAs_{0.66}Sb_{0.34}$ material and the contact resistance (and transfer length) associated with the Ti/Pt/Au contacts. The CTLM patterns consisted of inner contact pads with a radius of 40 μm and a large, outer contact pad with spacings of 5, 10, 15, and 20 μm from the inner pads. Measurements were made using a four-point probe setup with a bias current of 10 mA. The results of the CTLM measurements are shown in Fig. 1. The sheet resistances and transfer lengths were determined using the following equation for the resistance of the CTLM patterns:

$$R = \frac{R_{sheet}}{2\pi}\left[\ln\left(\frac{r_o}{r_i}\right) + \frac{L_T}{r_i}\frac{I_0(r_i/L_I)}{I_1(r_i/L_I)} + \frac{L_T}{r_o}\frac{K_0(r_o/L_I)}{K_1(r_o/L_I)}\right] \quad (1)$$

where R is the measured resistance (Ω), R_{sheet} is the sheet resistance (Ω/sq), L_T is the transfer length (μm), r_i is the inner contact pad radius (40 μm, in this case), r_o is the outer contact pad radius (i.e. the inner contact pad radius, r_i, plus the relative spacing: 5, 10, 15, or 20 μm), I_0 and I_1 are modified Bessel functions of the first kind, and K_0 and K_1 are modified Bessel functions of the second kind [8].

The extracted R_{sheet} and calculated specific contact resistance (r_C) for sample A ($InAs_{0.66}Sb_{0.34}$, $n = 2.0 \times 10^{17}\ cm^{-3}$) were 23.8 Ω/sq and $4.3 \times 10^{-8}\ \Omega\ cm^2$, respectively. For sample B ($InAs_{0.66}Sb_{0.34}$, $n = 2.6 \times 10^{18}\ cm^{-3}$), R_{sheet} and r_C were 4.5 Ω/sq and $2.4 \times 10^{-8}\ \Omega\ cm^2$, respectively. Sample C ($In_{0.27}Ga_{0.73}Sb$, $n = 2.5 \times 10^{18}\ cm^{-3}$), R_{sheet} = 13.8 Ω/sq and $r_C = 2.4 \times 10^{-5}\ \Omega\ cm^2$. The complete results of the Hall effect and the CTLM measurements are summarised in Table 1.

Table 1: Summary of Hall effect and CTLM measurements

Sample	A: $InAs_{0.66}Sb_{0.34}$	B: $InAs_{0.66}Sb_{0.34}$	C: $In_{0.27}Ga_{0.73}Sb$
Carrier concentration, n	$2.0 \times 10^{17}\ cm^{-3}$	$2.6 \times 10^{18}\ cm^{-3}$	$2.5 \times 10^{18}\ cm^{-3}$
Mobility, μ	14000 $cm^2/V\,s$	5600 $cm^2/V\,s$	4370 $cm^2/V\,s$
Calculated sheet resistance, R_{sheet}	22.3 Ω/sq	4.3 Ω/sq	11.4 Ω/sq
Extracted sheet resistance, R_{sheet}	23.8 Ω/sq	4.5 Ω/sq	13.8 Ω/sq
Transfer length, L_T	0.43 μm	0.74 μm	13.07 μm
Specific contact resistance, r_C	$4.3 \times 10^{-8}\ \Omega\ cm^2$	$2.4 \times 10^{-8}\ \Omega\ cm^2$	$2.4 \times 10^{-5}\ \Omega\ cm^2$

Calculated R_{sheet} determined using Hall effect measurements; extracted R_{sheet} found by fitting (1) to measured resistance (Fig. 1)

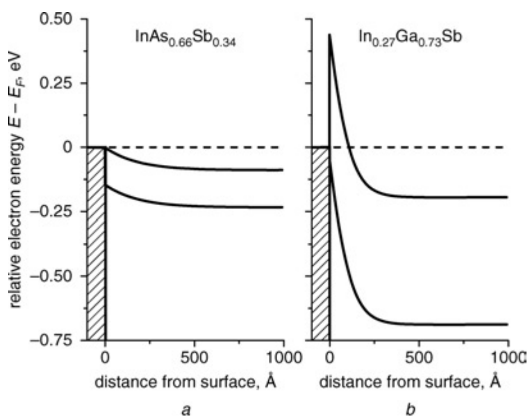

Fig. 2 *Band diagram of hypothesised n-type (Te: $2.0 \times 10^{17}\ cm^{-3}$) $InAs_{0.66}Sb_{0.34}$ contact, and of hypothesised n-type (Te: $2.5 \times 10^{18}\ cm^{-3}$) $In_{0.27}Ga_{0.73}Sb$ contact*

a (Te: $2.0 \times 10^{17}\ cm^{-3}$) $InAs_{0.66}Sb_{0.34}$ contact
b (Te: $2.5 \times 10^{18}\ cm^{-3}$) $In_{0.27}Ga_{0.73}Sb$ contact

The extremely low r_C for the $InAs_{0.66}Sb_{0.34}$ samples and its relative invariability with doping level is hypothesised to be due to the surface Fermi level pinning very near to or within the conduction band of the semiconductor, much like InAs (Fig. 2*a*). Conversely, the higher r_C for the $In_{0.27}Ga_{0.73}Sb$ sample is hypothesised to be due to the surface Fermi level pinning very near to or within the valence band of the semiconductor, much like InSb and GaSb, resulting in a barrier for electron flow into the material (Fig. 2*b*) [9]. This hypothesis would also agree with the extremely low r_C seen for p-type $In_{0.27}Ga_{0.73}Sb$ [10].

From Table 1, it can be seen that the calculated R_{sheet} from the measured Hall effect concentration and mobility agrees well with the extracted R_{sheet} from the measured CTLM results. Comparing the measured r_C to those of other contact results shows that equivalently low resistances can be achieved with $InAs_{0.66}Sb_{0.34}$ and Ti/Pt/Au contacts at relatively lower dopings and without a contact anneal (Fig. 3) [11–14].

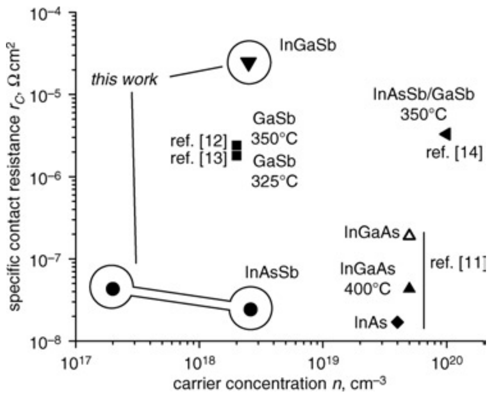

Fig. 3 *Comparison of r_C for various contact schemes*

Anneal temperatures (or maximum anneal temperature for multi-temperature processes) noted. Schemes without anneal, no temperature noted [11–14]

Conclusions: Low resistance, unannealed, ohmic Ti/Pt/Au contacts to *n*-type $InAs_{0.66}Sb_{0.34}$ have been demonstrated. Relatively high mobilities and associated low sheet resistances were measured. For the $InAs_{0.66}Sb_{0.34}$ sample doped at 2.6×10^{18} cm^{-3} (5600 cm^2/V s), a specific contact resistance of $2.4 \times 10^{-8}\ \Omega\,\text{cm}^2$ for a Ti/Pt/Au (100/50/2500 Å) contact scheme was measured. To date, this is the lowest measured contact resistance to *n*-type $InAs_{0.66}Sb_{0.34}$. Compared to other contact schemes, both annealed and unannealed, the combination of *n*-type $InAs_{0.66}Sb_{0.34}$ with a Ti/Pt/Au contact shows great promise as a lattice-matched contact scheme for high-speed, low-power 6.2 Å-based HBT operation.

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